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Synergy benefits in combining CCS and geothermal energy production

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Abstract

When injecting CO_2 in to a subsoil aquifer for permanent CO_2 storage the pressure build up in the regional area encircling the site can extend far beyond the site delineation and mitigation procedures must be considered.
The pressure build up can be controlled by production of water from the aquifer. In that context the synergy effect by combining CCS with geothermal energy production (GE) is obvious; *i.e.* the injection site for CCS may be surrounded by several GE plants, where the GE plants are operated so the net production of water can balance the injected CO_2 from the CCS operation sufficiently. Furthermore, the CO_2 plume migration may be controlled by operating the different sites as pressure sinks and sources. The paper illustrates the concept for an area in the northern part of Denmark, where a potential CCS site is characterized together with four prospective locations for GE plants. The GE plants are located in a radius of up to 10 km from the CCS site but still outside the closure of the CCS site. The Eclipse 100 reservoir simulator is used for simulations.

Keywords: Geothermal energy production; geological CO_2 storage; regional model; pressure propagation

1. Introduction

In the oil and gas industry voidage replacement is a technique used to balance undesirable pressure reduction, when operating a hydrocarbon field; here a given volume of water is injected to replace the produced hydrocarbon volume. For a geological CO_2 storage operation (GCS) the technique can potentially be applied to avoid undesirable pressure increase; here a given volume of water can be produced to balance the injected CO_2 volume. A synergy benefit by combining a GCS operation with the

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operation of production of geothermal energy (GE) seems obvious. Simulation studies have shown that the pressure wave propagates much faster and wider than the CO_2 plume and affects subsurface volumes that exceeds the extend of the plume (Birkholzer *et al.* [1]).

The geological setting for the two technologies can to some degree be similar, *i.e.* porous and permeable sandstone layers in the subsoil constituting a reservoir or aquifer and in a depth range from approximate 1000 – 3000 m. In more shallow reservoirs the temperature will be insufficient together with the unfavourable thermodynamic state of the CO_2 phase. At greater depth the reservoir rock permeability will be limited. The hydraulic capacity and the extension of the reservoirs are critical parameters for the success of the two technologies. An additional demand for a GCS site is the existence of a structural closure of the reservoir combined with an overlying caprock or another type of trap configuration.

The benefits for the GE plants are predominantly in the early site characterization phase, were shared exploration and appraisal cost can reduce the investments for the individual GE development projects. Benefit for the GCS operation is both in the exploration phase and in the operation phase, where pressure propagation can be mitigated through the GE operations, and to some degree in the post injection phase where the GE wells can be used as monitoring wells.

The present study illustrates the concept for an area in the northern part of Denmark, where the Upper Triassic – Lower Jurassic Gassum Formation is the target aquifer. The Vedsted structure, a structural closure in the Gassum formation with an overlying caprock may be a potential storage complex for a GCS operation. Approximate 30 km east of the Vedsted site is located the Nordjyllandsværket power plant, where a possible CO_2 capture plant may deliver industrial scale CO_2 stream to the GCS site. It is further assessed that the Gassum Formation may be a suitable aquifer for geothermal energy production for the area, which comprises a number of minor villages with combined heat and power plants for district heating.

Relevant geological and geophysical data are analysed to characterise and delineate the reservoir formation. Geological models and reservoir simulation models are constructed and used to investigate a number of scenarios of combining GE and GCS. Simulations of different scenarios, *e.g*. number of CO_2 injection wells and injection strategy on the GCS site together with the number and restrictions of the participating GE plants, are presented. Both site specific and regional models are used in the study to capture the scale of the problem together with boundary condition issues when solving the problem. The Eclipse 100 reservoir simulator is used for reservoir simulations. It is per default an isotherm simulator and the optional temperature module is not used in the present work as it is the regional pressure development that is in focus.

Supplementary it is assessed that commercial deployment of a GE plant is more unproblematic and faster achievable than the development of an industrial scale GCS operation so any public perception issues could only benefit from the combination.

2. Model construction

2.1. Static model

The regional geological model was constructed from a Top Gassum map (Britze et al., 1991 [2]) and the Vedsted-1 well, an old hydrocarbon exploration well. The regional model covers an area of 100 km x 100 km and is centred around the Vedsted-1 well. Different grid resolution is used; 100 x 100 x 40 and 132 x 124 x 40, where the second grid is refined in the inter-well area to resolve the CO_2 plume extension in more details. Lateral grid cell size varies between 1000 m x 1000 m and 200 m x 200m. A vertical grid size of 8 m is used. The structural closure covers an area of approximate 10 km x 16 km. The model is shown in Figure 1.

The model is populated with porosity data interpreted from wireline log data from the Vedsted-1 well, and permeability data derived from a relation between porosity and permeability determined from core analysis data (Figure 2).

The model is a layer-cake model, which is sufficient in the present study as pressure is not highly sensitive to minor variations in reservoir properties. Faults will of cause impact on the pressure distribution but is not included. The regional geology in the study area for the Gassum formation is assessed to be relative un-dramatic.

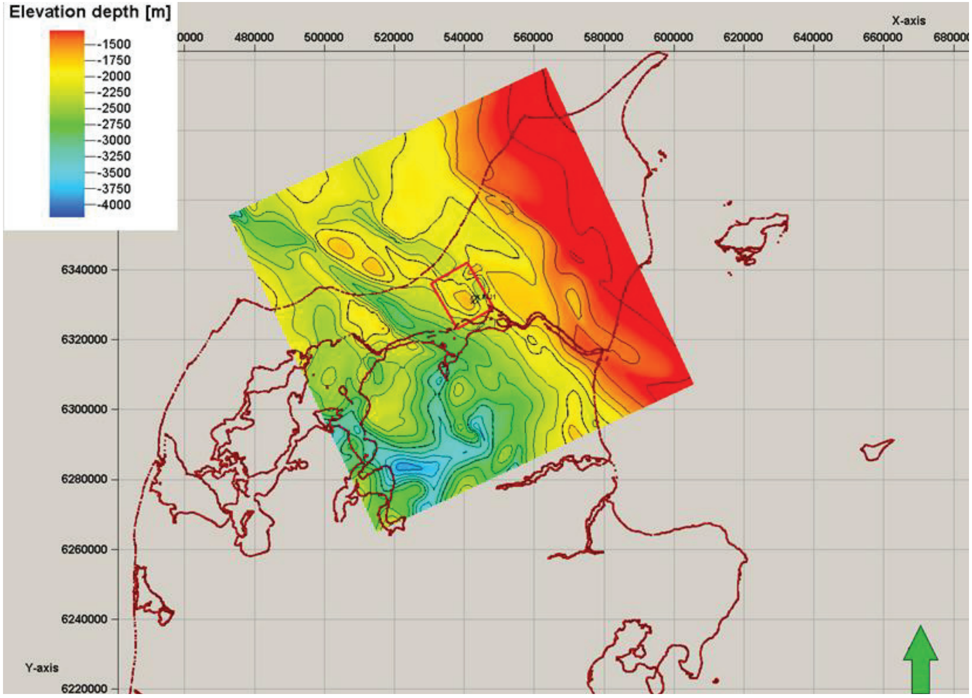


Figure 1. Model area in northern part of Denmark. Vedsted structure delineated by red polygon.

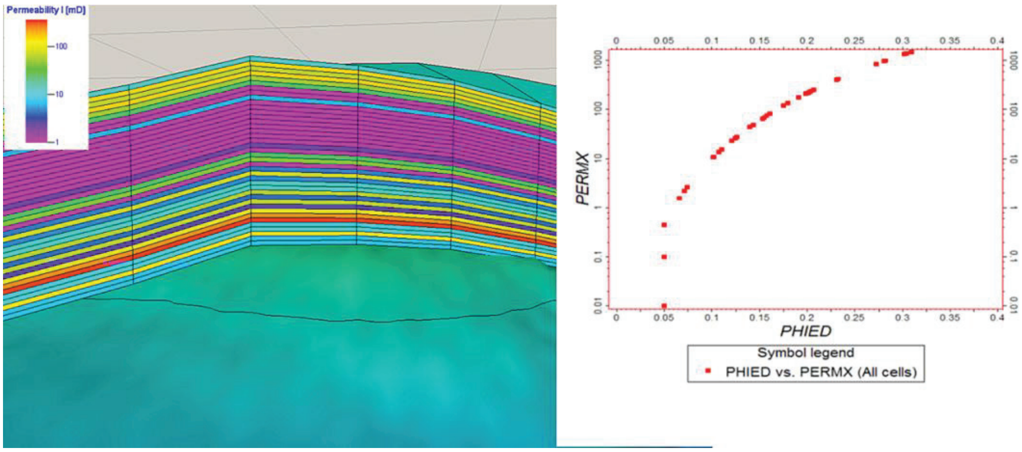


Figure 2. Cross section through model showing vertical permeability variation. A low permeability layer separating an upper and lower reservoir section with relative high permeabilities.

2.2. Dynamic model

Eclipse 100 black oil reservoir simulator [3] is used for reservoir simulations of the different injection and production scenarios. The simulator is run in the default isothermal mode.

When dealing with a CO_2 – brine system Eclipse 100 can be used simply by treating the CO_2 and brine phases as the simulator gas phase and simulator oil phase, respectively. Fluid data descriptions were taken from the literature [4-6]. Saturation functions were taken from the work of Bennion & Bachu [7,8].

The Eclipse well option is used to describe the dynamic behaviour of the wells. Wells were controlled by rates (surface conditions). A bottom hole pressure (BHP) limit was set in order to avoid any extrapolation of the PVT tables in the wells. Wells are placed vertical in the reservoir and are completed in the entire reservoir section.

A “pore-volume multiplier” option is used as boundary condition. The pore-volume multiplication is controlled by the MULTPV keyword in Eclipse. The pore volume for the outermost grid cells is then multiplied with the factor set by the MULTPV keyword.

Initially the simulations are started from hydrostatic pressure equilibrium. The injection schedule for CO_2 injection was a constant rate of 3.15 MT/year for a period of 40 years. Injection scenarios with a single injection well and with two injection wells are studied. Four production wells are placed around and outside the structural closure to mimic the net water production from four GE plants. The location of the individual GE plants is fixed by the actual location of four minor cities in the region (Figure 3).

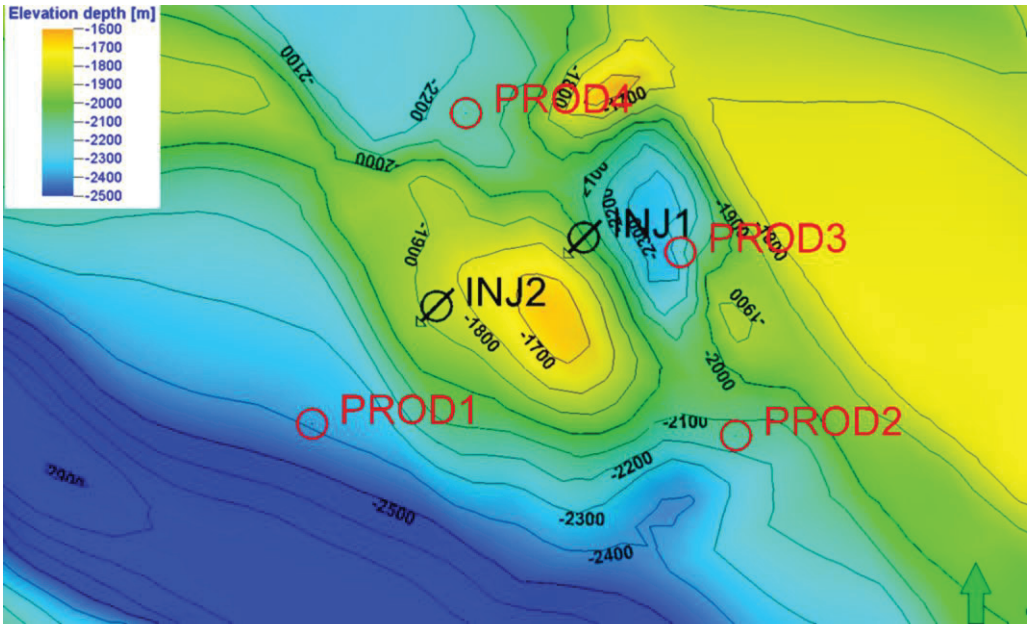


Figure 3. Well locations. Injection well(s) placed down flank on the Vedsted structure. Production wells placed around and outside the structural closure.

3. Scenarios

Base case scenarios with only CO_2 injection are simulated to illustrate the pressure development during an injection period of up to 40 years of constant injection from a single injection well. 40 years is assessed to be an approximate lifetime of a CCS project from a single power plant.

For the base case scenarios the boundary conditions are evaluated by varying the value of the MULTPV keyword. If a too high MULTPV value is used the pressure at the boundaries tends to be kept constant at hydrostatic pressure level meaning that the pressure can't propagate freely when the pressure wave reach the boundary of the model leading to erroneously simulation results.

From the base case runs the amount of injected CO_2 given in reservoir volumes can be matched by an equivalent volume of net production of water from the four GE plants resulting in a 100% voidage balance. When operating a GE operation it is normal to re-inject the produced and cooled formation water after energy production. The re-injection helps maintaining the pressure support for the production wells but another important issues is securing discharge opportunities of the cooled GE water. There is an obvious conflict in maintaining 100% voidage replacement for the GCS operation and the need for re-injection of the GE production water.

Simulation cases with different volumes of net produce GE water are constructed to investigate how far from a 100% voidage replacement the combined GCS and GE operations can be performed without stressing the individual operations.

A case with two CO_2 injection wells is simulated to investigated the effect on the pressure development when the same constant injection rate as for the base case runs, is distributed from two injection points some distance apart.

Spreading the injection points can also make the filling of the structure more efficient and thereby increasing the storage capacity. Another method to increase filling efficiency can be to control the GE operations; the individual GE operations acts as pressure sinks and the magnitude of the pressure sink can guide the direction of the CO_2 plume by controlling the net production differently between the GE plants.

4. Results and discussion

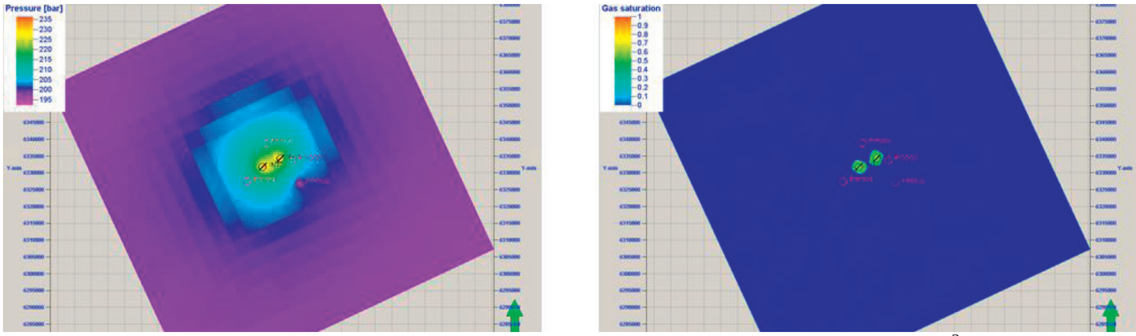
Figure 4 shows the pressure and CO_2 plume distributions after 40 years of injection from two injection wells and four GE plants operating simultaneously. Pressure is calculate as the water potential to avoid gravitational overprint on the distribution. The net production from the GE plants is 30% of the injected CO_2 volume at reservoir conditions, *i.e.* a voidage balance of 70%. The total net production rate is approx. 165 m^3/h. The GE plants are operated unsymmetrically; the southern-most GE plant (PROD2 *cf.* Figure 3) is creating the largest pressure sink by handling 66% of the net production, the three other GE plants are operated uniformly. The motivation for this production configuration is to push the CO_2 plume to the south east for an efficient filling of the structure.

Figure 5 shows pressure (water potential) profiles in a SW to NE direction through the injection well(s) on the storage site through the entire model for different simulation cases.

Figure 5A illustrates how the pressure propagates through time for the base case scenarios. After approximately 20 years of CO_2 injection the pressure profile reaches the boundary of the model and handling of boundary conditions becomes crucial.

Figure 5B shows how different choice of MULTPV values affect the pressure profile at the model edges. It may be argued that there is no control on the exact MULTPV value for boundary condition, as the model is not large enough to evaluate how pressure will develop outside the 100 km wide model, an even bigger model could be considered [9]. For the present study with a combined net production of water to balance the pressure increase the model size is assessed to be sufficient.

Figure 5C illustrates the concept of pressure management through a controlled voidage replacement below 100%, a voidage displacement of 70% does have an effect on the magnitude of the pressure



propagation, but to maintain a replacement ratio as high as 70% approximate 150 m^3/h produced GE water can't be re-injected in to the formation but has to be managed in another way.

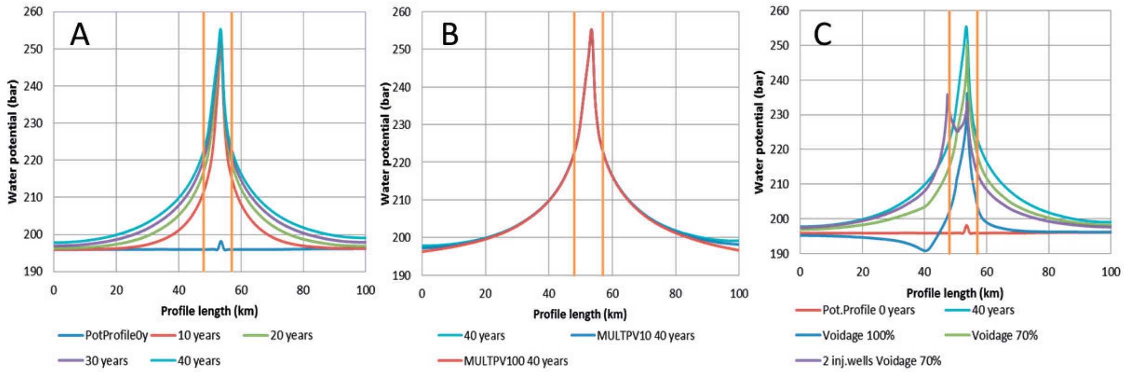


Figure 4. Pressure (water potential) and CO_2 plume distributions after 40 years of constant CO_2 injection (Injection rate: 360 T/h) and a net production of water of 160 Sm^3/h.

Figure 5. Pressure (water potential) profiles for SW to NE direction through the model. The orange vertical lines indicates the delineation of the storage site. The profiles covers the entire 100 km of the model. A) Base case scenario for different times of the injection scheme. B) The effect of boundary conditions after 40 years of injection, base case scenario. C) Pressure (water potential) profiles for different scenarios of operating GCS and GE in combination.

5. Conclusions

Study performed to show synergy effects for GCS and GE operations.

- Regional pressure propagation from CO_2 injection mitigated by net water production from geothermal energy production plants.
- Benefits through shared exploration and development costs.
- GE plants must be compensated during the operating phase for handling a net production of formation water.
- GCS site can benefit in the injection and post-injection phases from a number of potential monitoring wells.

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